Ludwig Lange, "New experiments on the process
of the simple reaction to sensory impressions."

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Translated by David D. Lee ©2009.[1]

First article with four woodcuts.[2]

The experimental investigations reported here have their origin in a special question, namely the influence of anticipation on the apperception[3] of sensory impressions. There is no doubt that apperceptive registration of a stimulus takes place more quickly when the recipient is more expectant of it. The experiment described below is the only way to clarify the objective meaning of the influence of anticipation.

This type of experiment takes advantage of *reaction time measurement* experiments often employed in similar studies. We expected these increases or reductions of apperception to be expressed via parallel increases or reductions of reaction time. We also expected that even if we were not able to determine the various values of apperception itself, we could at least report their differences.

More difficult than comparative reaction time measurement

--- p. 479 / p. 480 ---[4]

is the problem of how to measure the degree of anticipatory tension. One need only briefly consider the matter in order to realize that we do not now have a direct,

[1] [Explanatory footnotes appear in brackets. The translator wishes to thank Nadja Stumpf, Dr. Stefan Petri and Prof. Dr. Axel Karenberg for their able and kind assistance. Please forward corrections and relevant annotations to davidleeinamsterdam@gmail.com. Some two pages of this text appeared in English earlier in Solomon Diamond's The Roots of Psychology (Basic Books: NY, 1974, pp. 707-710).]

[2] [There was no follow-up to this article due most likely to Lange's battle with mental illness which forced his departure from the Institute in 1887.]

[3] [introspective self-consciousness]

[4] [These numbers indicate page breaks in the original publication.]

objective measure of this. It also presumes that the apperception duration be established by direct measurement, as is often done in other cases. Even if we had these, the experiment would simply produce useless results. One must thus approach the matter from another direction for in this way we may nonetheless expect certain provisional results as a basis for further investigation.

From the moment the test subject was signaled that the event was about to take place, the previously minimal degree of expectation rose continually, remained at its maximum, but eventually resulted in convulsive oscillation. If the temporal interval between signal and primary stimulus (i.e., that which is to be reacted to) is deliberately set long, then the latter took place at various high degrees of anticipation. Furthermore, if the various intervals of these corresponding reaction times are measured, the coordination of joint values of given functions will offer enough clues in order to be able to shed some light on our original question.

Research into the dependence of the interval and the reaction time are incidental and to a certain degree already communicated by others. I shall return to this idea shortly.

The sense which we began to experimentally examine was hearing. For this task it is easiest to employ a well-thought out experimental plan, such as the one I here describe.

--- p. 480 / p. 481 ---

I. Instructions for Sound Reaction Experiment and the Basis for the Calculation of Measured Time

The most striking characteristic of our instructions is that the experimenter and the object of psychological investigation (test subject) remain in separate, distant rooms as detailed by Tigerstedt and Bergqvist.[5] A signal to the test subject was provided from the experimenter's room by an electric bell. The primary input sound was caused by the release of an electromagnetic hammer[6] which loudly struck a piece of metal directly beneath it.

This two-room approach is particularly useful and we recommend it highly, for in this way noises from the equipment which may distract or disturb are made innocuous. For our purposes this was essential because preparing the equipment for use before each experiment was a noisy affair which, if we had not used this approach, would have resulted in the contamination of the required experimental conditions.

In addition to the signal bell and the electromagnetic hammer, the only item remaining to complete the setup for the sound reaction experiment is the reaction key. This key is basically the same as all others used to date.

To measure time we employed the older model Hipp chronoscope; we made use of a number of Meidinger elements as a galvanic battery which we attached to a

--- p. 481 / p. 482 ---

commutator. This electrical time measuring setup does not otherwise essentially deviate from that provided in Wundt's classic text.[7] In our Figure 1[8] (B) is the battery. From the commutator (C) the signal branches, one passing through the chronoscope (Ch) and the rheochord (Rh) back to the

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[5] *Zeitschrift für Biologie,* Kühne & Voit (Eds.), vol. XIX.
[6] The same hammer used by Estel in his time sensory experiments, see *Phil. Stud.*, vol. II, p. 51.
[7] *Physiol. Psychologie*, vol. II (3rd ed.), p. 274 f.
[8] In this and subsequent figures all connecting wires not directly related to time measurement are omitted. This is why the electromagnets 1, 2, 3, 4 do not appear to be connected to anything and why the signal bell is missing altogether.

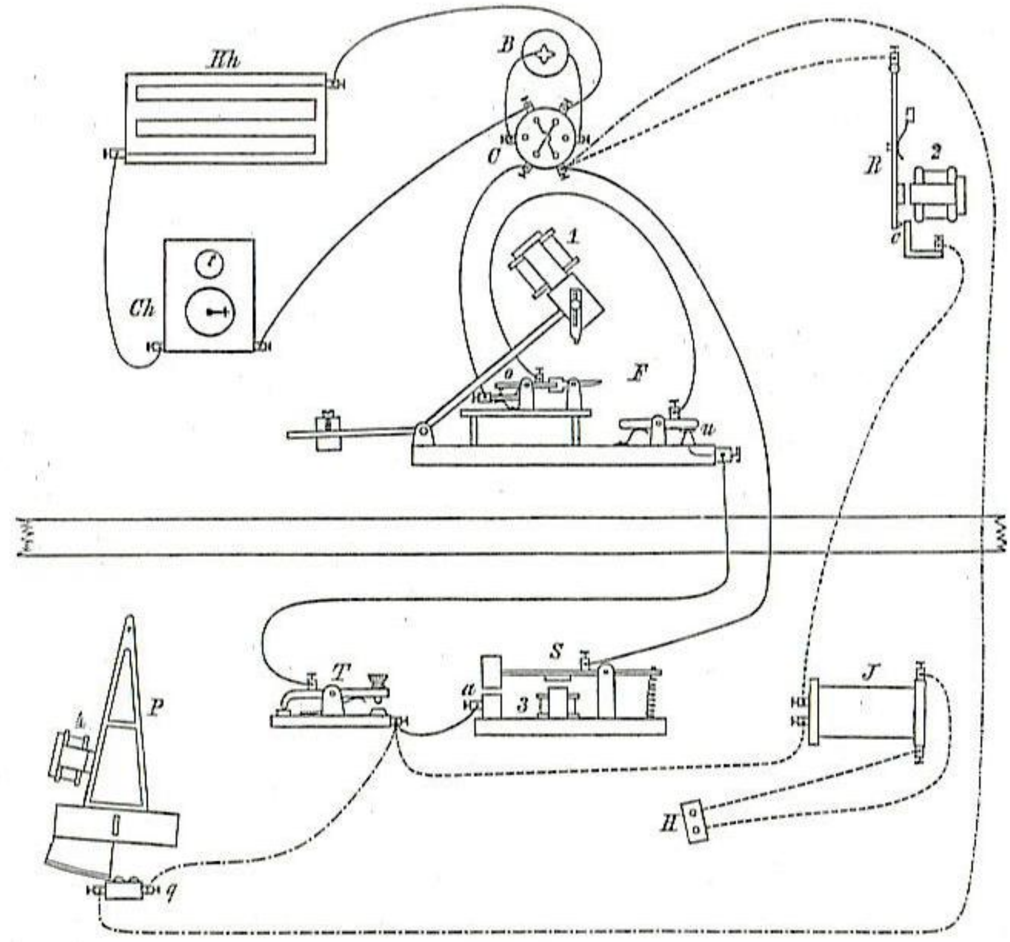

Fig. 1.

commutator. The other branch passes into the test subject's room directly to the hammer (S) and from the strike plate (a) to the reaction key (T) and thence back

--- p. 482 / p. 483 ---

to the first room and the commutator[9]. On its way back, however, we redirected it through a control apparatus (F) which permitted us to determine whether resulting false chronoscope readings[10] are due to excessive or insufficient current from the (otherwise very reliable) battery. In short, this allows us to determine the respective amount of "electromagnetic correction" which is then always taken into account. We

[9] [A device for reversing the direction of a current.]
[10] See Berger, *Philos. Stud.*, vol. 3, p. 45.

did not employ the *Fallchronometer* used by Cattell[11] as our control apparatus, for despite our best efforts it did not appear to be constant enough. Rather, we simply modified Berger's instrument *(Fallhammer)* which initially establishes contact at (o) then for a constant and regulated time ("control time") later breaks contact at (u). As the hammer employed by Berger was not capable of providing the one-tenth of a second control time we sought, we lengthened the handle of the hammer above the fulcrum and attached a weight for equalization which permitted the measured reduction of the speed at which the hammer fell. Furthermore, during the course of the experiment we replaced the upper Berger hammer contact with a mounted, non-sliding, platinum contact in order to avoid the inaccuracies which changes in height and accumulated dust in the mercury might cause. The control time was determined either directly via a tuning fork of known frequency or by use of a chronograph. This always produced 150σ (where σ = one one-thousandth of a second). When the control time was measured with the chronoscope (for which

--- p. 483 / p. 484 ---

the reaction and hammer contacts must naturally be closed), it did not register its true value, but the correct value is calculated by taking into account the "electromagnetic correction." When ten consecutive chronoscopic measurements of the control time are taken, the middle of these ten values varied by only 0.8σ, often by merely 0.5σ and never more than 1.0σ. Such extraordinary precision absolutely guarantees the exactitude of our experimental results.

During actual reaction tests the hammer contacts *o* and *u* must naturally be closed so that current can flow freely through them.

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[11] *Philos. Stud.*, vol. 3, p. 306ff.

In order to obtain an exact time interval between the bell and the hammer we employed a pendulum whose (back and forth) swing[12] was exactly one second. When set in motion, this pendulum automatically activated a platinum-mercury contact at its nadir once a second[13]. This contact was simultaneously connected to two circuit lines: one to the bell and the other to the hammer. Each of these lines was also equipped with a springy mercury contact which could be temporarily closed with a finger. Pressing either of these contacts for a longer period of time resulted in either the bell ringing or the hammer striking on a full [i.e., not a fraction of a] second. Clearly one could activate the contacts such that the bell was immediately followed by the hammer precisely one, two, three or four seconds later. It was not possible to know beforehand whether it would be necessary to measure fractions of seconds. Should this need arise we would have to lengthen the pendulum's swing. Only for intervals of less than one second was it necessary to employ a special apparatus.

--- p. 484 / p. 485 ---

The signal bell also served the purpose of permitting the experimenter to communicate with the test subject. The reverse was also true by means of an electric bell. There is little point in further detailing this primitive signal system here. Speaking methodologically, however, it is worth mentioning that by means of this system the test subject himself immediately indicated incorrect reactions and these times were consequently struck from our calculations. This leads me to several points regarding the consideration of the individual results as authoritative.

I have limited the exclusion of abnormal reaction times to the following cases:

1) As indicated above, all reactions the test subject indicates as false are not included.

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[12] [*Doppelschwingung*]
[13] [Or rather once every half-second?]

2) In as much as the first two or three measurements deviate considerably from subsequent measurements they too are safely excluded. Ordinarily a few test runs are made before the test subject is accustomed to the procedure and learns to concentrate.

3) It is often the case that measurements made immediately after a false start differ strikingly from the average and indicate that the test subject was distracted by his false reaction. In this case I permitted these results to be excluded as well.

4) If the "interval" is held constant (through a series of tests) and in addition the time between succeeding test runs (the "period") is short (20^{S} or less), under certain circumstances it is easily possible that by virtue of repetition the test subject (more or less consciously) reacts too quickly and activates the registration key simultaneously with the primary signal, just as a hunter may shoot ahead of his quarry. Such data

--- p. 485 / p. 486 ---

are naturally not true reaction times,[14] but their extraordinary small, often even negative quality activates the chronoscope only barely or not at all. Naturally such values may not be included with true reaction times or used to calculate averages. In our trials most of these were almost always caught by the test subject, however. Nonetheless, a negative or particularly small reaction time would occasionally appear which was not caught. On what basis were we to decide whether this measurement should be excluded as suspect? Where should the border between suspect and acceptable reactions be set? In order to establish this border I have as much as was possible also conducted test runs with variable intervals, i.e., series in which the interval was set unpredictably to one, two, three or more seconds. The minimum

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[14] See Berger, *Philos. Stud.*, v. 3, p. 48.

times generated by this were taken as the lowest threshold of acceptability and results smaller than this were excluded.

As it is of importance for future research, I wish to stress that the number of premature reactions can be reduced to almost zero in the following ways:

1) test subject practice;
2) giving a full thirty seconds to the testing period. This has the beneficial effect of giving the test subject sufficient time to invalidate his reactions, as needed;
3) the test subject concentrates completely on focusing his attention first and foremost on the signal. This measure was in any case indispensable if one wanted to correctly test the length of the interval. In addition, it had the advantage that the test subject did not unnecessarily waste his attention and slowly yield to fatigue.

If the test subject handles himself poorly he is excluded from the experiment. In particular, runs in which

--- p. 486 / p. 487 ---

nervous fatigue generated inconsistent results were rejected.

The arithmetic results were constructed in rows of twenty to thirty, most near twenty-five, runs.

II. Facts regarding two different methods of reaction: muscular and sensory reactions.

Because psychometrics is practically and in particular methodologically an undeveloped discipline, it is essential that one begin an investigation of any importance with a set research plan; such a plan must always be modified in practice, however. Indeed one always proceeds from certain questions and must always take different possible perspectives into account. Yet in most cases unforeseen results during the course of the investigation offer compelling cause to desert the original thrust of the project and turn to other topics. While busy with the first practice trials we were confronted with a question whose answer was one of the most important conditions for permitting further progress.

The favorable influence of silence and isolation on the test subject as well as the comparatively long time the experiment takes permit a certain distancing from the *subjective* conditions of each attempt and therefore a kind of belated accountability. To a certain degree this gives rise to speculation as to its influence on the speed of the reaction, that is whether the test subject's anticipation was concentrated fundamentally more on the sensory stimulus to be perceived[15] or the reaction movement to be performed. In point of fact our experience taught us that:

1) On one hand we were able to record reactions of when the test subject did not think *at all* about the imminent sensory stimulus, but rather concentrated as much as possible on preparing their own reaction.

--- p. 487 / p. 488 ---

2) On the other hand, by *strictly avoiding* any preparatory motor innervation the test subject can concentrate his entire preparatory attention on the anticipated sensory input and simultaneously focus on the immediate conversion of the impulse to movement. Such reactions are completely different from the first sort as regards their psychological meaning as well as duration.

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15 [By this Lange means the sound.]

It is recommended that both sorts of reactions be given some kind of designation to express as aptly as possible the *purely factual characteristics* of the response conditions. In this sense the first class of reactions may be termed "extreme muscular reactions." By this we do not mean to imply that muscular movement in the second type of reaction is insignificant, but only wish to emphasize that the test subject was thinking exclusively about his attention to the preparation of those muscles which react. In contrast, those reactions of the second class, characterized by the greater exclusive attention to sensory input (i.e., principally the avoidance of preparatory movement innervation), are known as "extreme sensory reactions."

The following remarks are relevant to both classes of reactions. What must be stated first regarding the muscular reactions is a warning against misunderstanding the preparatory innervation of movements essentially as the release of an existing tension. This is in no way the case. However, minimal muscular tension and related muscular sensations of a *secondary* nature are often present, yet the degree of sensitivity is, in our experience, absolutely not relevant to whether the preparatory innervation was successful. Additional trials designed to test whether tensing of the flexor

--- p. 488 / p. 489 ---

and extensor resulted in essentially different reaction times compared to when such tension was held to a minimum and occurred secondarily were not significant. The most that can be said is that the influence of muscle fatigue is greater there than here.[16]

On the other hand, the complete absence of (even the smallest) muscular perception is indeed a reliable criterion to determine whether it serves as a primary condition of extreme sensory reaction (avoidance of all preparatory movement

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[16] Analogous is the customary preceding visual imagination of the movement of the arm which is of only secondary importance, as the reaction's precision is not dependent upon it.

innervation). Some time is needed to become familiar with the routine before the test subject is able to achieve the ideal sensory reaction. They usually begin by over reacting and then enter a stage of strikingly long reaction times – considerably longer than those reported below. This is because test subjects have learned to avoid the preparatory movement innervation, but have not yet achieved the [required] agility when going from sensory impression to reaction. The test subject perceives either a sensory input which is not part of a train of thought or is assimilated with earlier memories of the input. Such reaction times are consequently not to be regarded as valid reaction times. Only when the test subject is able to master the most precise coordination of his reactions to the input by virtue of a great deal of careful repetition will times be obtained which may be regarded as typical sensory reaction times. For this reason the acquisition of good sensory reactions is obviously more difficult than exercising muscular reaction because in that case (as opposed to this one) everything depends on not doing two (opposing) things: the preparatory innervation of the reaction movement and unnecessary delay of the volition impulse.

As far as it is based on the existence or absence of the preparatory movement

--- p. 489 / p. 490 ---

innervation, one can differentiate between muscular and sensory tension in the following way. It is assumed that the test subject's arm lies on a support which, unbeknownst to the test subject, can be quickly removed. If the test subject has his arm muscles tensed for action and the arm support is suddenly removed, the arm will reflexively be pulled up and remain raised. If instead a preparatory innervation has been successfully avoided, then the arm will simply fall when the support is removed.

The designation of these fundamentally different reactions as "extreme muscular" and "extreme sensory" is done deliberately. It virtually goes without saying that there is a middle road between these two extreme methods: dividing tension between hand and ear.[17] Naturally these middle ways cannot lay as much claim to our interest as the more extreme forms, because they are difficult to check. Both arithmetically as well as in their average variation recorded, reaction times lie in general between the extreme muscular and the extreme sensory.

With respect to the extreme methods, however, we must not forget that the *degree of expectation tension* is exactly the same in both cases and only its direction differs. This deserves to be stressed as a misinterpretation of the experimental data could lead to the assumption that the extreme sensory reactions are simply reactions taken during an inattentive moment. Anyone with experience in these things would immediately reject such a superficial interpretation.

The completion of these preliminary remarks permits me to introduce the first data obtained through successive, comparative

--- p. 490 / p. 491 ---

test trials of both [types of] reactions. As is custom, *a.m.* indicates the arithmetic mean, *m.v.* the average variation of the trial run (both expressed in σ = 0.001 second units), *n* the number of reactions from the trials actually used in our calculations. *J* represents the "interval" between signal and primary impression, *Π* the "trial period". I must also report the following regarding the interval. Lacking a particularly good way to set a specific interval for sensory reactions – one which would allow us to examine extreme sensory tension – we calculated average values taken from various intervals. In muscular reactions, however, the fact arose (and was confirmed by self-

[17] [Prof. C. Green observed: This turn of phrase used by Lange is interesting because it is very close to what Angell & Moore say in their 1896 "solution" to the problem: "The hand therefore is stimulus as well as response to the ear, and the latter is response as well as stimulus to the hand. Each is both stimulus and response to the other. The distinction of stimulus and response is therefore not one of content, the stimulus being identified with the ear, the response with the hand, but one of function, and both offices belong equally to each organ."]

perception) that in general a certain interval, and indeed for various test subjects not always that which was most favorable, [was needed] in order to achieve the extreme muscular reaction. This interval is, as much as is possible, presented in the following tables. After 1 July 1886 Period *Π* was set longer in muscular compared to sensory reactions (40s rather than 30s) because it was too difficult for relatively unskilled test subjects to avoid reacting too early when set at or less than 30s.

The following constitutes our initial, preliminary results. See Table A below.

These figures cannot in any way be considered conclusive; rather one may expect that the difference in reaction times would increase somewhat with progressive practice. On one hand, the lowest possible limit of extreme muscular times, such that they really corresponded to maximal muscular preparation, were not yet achieved. On the other hand, both test subjects agreed that their attempts to avoid any and all preparatory movement innervations during the sensory runs were not yet fully successful. Thus those sensory

--- p. 491 / p. 492 ---

Table A:

*N. L.**)						
Datum	Reactionsweise	*J*	*Π*	*a. M.*	*m. V.*	*n*
28/VI 86	musculär	2^s	20^s	116^σ	8^σ	21
,,	sensoriell	2	20	167	19	27
1/VII 86	sensoriell	3	30	172	21	25
,,	musculär	3	40	126	12	22
6/VII 86	sensoriell	1	30	170	20	25
,,	musculär	1	40	124	10	23
*B.**)						
Datum	Reactionsweise	*J*	*Π*	*a. M.*	*m. V.*	*n*
2/VII 86	musculär	2	40	137	11	24
,,	sensoriell	2	30	174	27	27

[18]

times are not to be considered *extreme* sensory. Nevertheless these tables demonstrate that average sensory reaction times as well as the associated average variations were always considerably longer than muscular reaction times independently of time interval [J] and amongst various individuals. With this fact established,

N. L.					
Sensorielle Reactionen					
Datum	*J*	Π	*a. M.*	*m. V.*	*n*
8/VII 86	1^s	30^s	222^σ	21^σ	25
,,	2	30	216	21	26
,,	1	30	232	19	25
	Gesammtresultat:		223^σ	20^σ	76
Musculäre Reactionen					
Datum	*J*	Π	*a. M.*	*m. V.*	*n*
12/VII 86	2	40	127	8	24
,,	2	40	124	11	26
13/VII 86	2	30	129	15	24
2/VII 86	2	30	122	11	25
	Gesammtresultat:		125^σ	11^σ	99

[18] My colleagues Nicolai Lange [N.L.] from Petersburg and Belkin [B] from Moscow. I should like here to voice my deepest thanks to all of my colleagues for their energetic support.

--- p. 492 / p. 493 ---

there can be henceforth no objections to comparing the results of various days, as in the following tables:

B.					
Sensorielle Reactionen					
Datum	*J*	*II*	*a. M.*	*m. V.*	*n*
10/VII 86	1^s	30^s	236^σ	36^σ	30
"	2	30	235	24	24
"	1	30	212	25	25
"	2	30	211	20	26
	Gesammtresultat:		224^σ	26^σ	105
Musculäre Reactionen					
Datum	*J*	*II*	*a. M.*	*m. V.*	*n*
9/VII 86	1	40	121	9	28
"	1	40	129	10	21
"	1	40	127	10	20
14/VII 86	1	30	133	8	22
15/VII 86	1	30	156	8	25
16/VII 86	1	30	150	10	25
"	1	30	138	11	23
	Gesammtresultat:		137^σ	9^σ	164

*L. L.**)					
Musculäre Reactionen					
Datum	*J*	*II*	*a. M.*	*m. V.*	*n*
24/VII 86	2^s	30^s	124^σ	9^σ	27
"	2	30	124	8	21
2/VI 87	variabel (1,2,3s)	30	121	9	25
	Gesammtresultat:		123^σ	9^σ	73
Sensorielle Reactionen					
Datum	*J*	*II*	*a. M.*	*m. V.*	*n*
26/VII 86	3	30	231	32	18
"	2	30	230	33	19
	Gesammtresultat:		230^σ	32^σ	37

[19]

Here in the "totaled results" row one finds that

--- p. 493 / p. 494 ---

[19] * [L.L.] is the author of this paper.

the *a.m.* (arithmetic mean) is derived from collected single trials, while under *m.v.* (the average variation of the trial run) the arithmetic mean from the average variations is notable.

These tables indicate that the sensory and muscular average difference is 98^σ for N.L., 87^σ for B. and 107^σ for L.L.[20]

Finally, I wish to state the results for a fourth test subject (Mr. Kolubowsky), noting however that while his results themselves have no definitively measurable meaning, the relation of muscular to sensory results does. We conjecture that not only is the applied interval (1s) not yet K's most favorable in order to reach *maximal* muscular preparation, but most importantly that this test subject's relative lack of practice should certainly not result in his sensory reaction being taken as extreme. In spite of this we report these data because they nonetheless help prove that the time differences are generally valid.

K.					
Musculäre Reaction					
Datum	*J*	*II*	*a. M.*	*m. V.*	*n*
12/XI 86	1^s	30^s	144^σ	9^σ	25
15/XI ,,	1	30	145	13	25
17/XI ,,	1	30	151	9	24
	Gesammtresultat:		147^σ	10^σ	74
Sensorielle Reaction					
Datum	*J*	*II*	*a. M.*	*m. V.*	*n*
17/XI 86	1^s	30^s	192^σ	24^σ	22

In addition to the four test subjects reported above, we also tested numerous other people's muscular and sensory reaction times all of which confirmed that the extreme sensory reaction times were measurably longer than the extreme muscular. There is really no point to presenting the results of these tests here as lack of test

[20] [These initials reference the tables.]

subject preparation [also] largely failed to generate meaningful results. There is something I would like to particularly emphasize at

--- p. 494 / p. 495 ---

this juncture. It was our experience that there are some people who despite having the same differential as others regarding the arithmetic mean of muscular and sensory reaction nevertheless could not bring themselves to react consistently through an entire test run notwithstanding repeated practice and concerted effort. Such individuals are too nervous and unable to concentrate and most do not even have the presence of mind due to mental excitation which causes them to fail to recognize their own errors. Naturally there is no benefit to normal psychology to working further with these obviously pathological individuals (an affliction which at any time can also strike those who believe their reactions to be normal).

Returning to our most reliable test results, namely those of test subjects N.L., B. and L.L., these data demonstrate that the average length of extreme sensory reaction (to sound) is about 85 to 100^{σ} longer than those of extreme muscular reactions. Furthermore, these data also prove that the *m.v.* (the average variation of the trial run), which is obviously also a measure for individual test variation within a series, averages 8 to 15^{σ} in muscular reactions, while varying between 20^{σ} and 40^{σ} in extreme sensory reactions. The theoretical importance of this fact will be discussed in the following section.

I take it as a virtually certainty that our experience demonstrates that for completely healthy people essentially “personal differences” do not exist when tested following *the same extreme method* and reacting to the heretofore described conditions. Despite their best efforts, a single person tested on separate days evidences a certain variation whose total is hardly less than the difference between individuals. What we took up to now entirely as the reducing influence of repetition on the reaction time (and the increased consistency of the results) is, I think, largely due to the fact that the test subject

--- p. 495 / p. 496 ---

unconsciously got used to reacting following the extreme muscular method. I believe the formulation described here permits a faster way to generate a "practice effect": nothing more is needed than for the test subject to try to carry out the conditions for extreme muscular reaction. Here too practice quickly leads to progress.

If we were to run uninitiated individuals through the tests intentionally not explaining the difference between the two kinds of reaction methods beforehand, some would chiefly give muscular, others sensory responses. With practice, however, their desire to react as quickly as possible would unconsciously lead most of them to a muscular reaction. Which of the two kinds of reactions any given individual *initially* prefers probably depends upon their temperament. Those with a great deal of motor energy immediately choose an almost extreme muscular reaction, while those of a more contemplative nature generally produce a sensory reaction.

I would like to take this opportunity to warn in the strongest possible terms against mass testing with people who lack the ability to analyze their own consciousness psychologically. The differentiated psychological conditions here, at least in so far as they are *conscious,* avoid control and results gained from such runs are either abortive or undifferentiated. The confusion which can be created by such uncritical methods needs no further explanation, given what I have described above.

I shall end this section by emphasizing a few of the differences in reaction types which appear to me to be of particularly great importance. The first of these is that the so-called early registrations (see page 485f) in extreme sensory runs are never found, while on the other hand they can be avoided in extreme muscular reactions only via special preventative measures (to be explained elsewhere). A second firm fact derived from our many test runs is that any unexpected, annoying stimulus of any other sense (e.g., sound reactions to an electrical or optical stimulus) generates an urgent response – often surprising the test subject – whereas in sensory reaction testing it remains unerringly even. One condition for this is that the vexing stimulus reaches a certain level of intensity. These two largely external facts lead to a third, exclusively internal one regarding consciousness: in extreme muscular reactions the test subject strongly believes he reacts *simultaneous* with or even sometimes before the sensory stimulus whereas in extreme sensory reactions he perceives with certainty that his reaction comes after the stimulus.[21]

I shall now analyze more closely the reaction process and specifically investigate the *psychophysical* essence of the different ways of reacting.

III. Theoretical comments on different ways of reacting

To my knowledge it has not been previously reported that there are essentially two different kinds of simple reactions. Indeed, one finds hints here and there that the reaction takes on an increasingly automatic character with "practice"; yet increasing concentration has been regarded as a sufficient explanation of this phenomenon to date and the fact that the *direction* of the reaction is of decisive importance has not been discussed. That is to say that at that moment the test subject's anticipation need *not* be focused *on the sensory stimulus* in order to achieve the most automatic

[21] [Prof. C. Green comments: I suspect the implicit claim here is that he is illicitly reacting to his initial perception, not to the full apperception of the stimulus – a critical distinction for Wundt.]

reaction. In other words, in truth one takes a qualitative difference as merely quantitative.

Under these conditions it was no surprise that *a generally valid* interpretation was attributed to the simple reaction process and that the large variances which were found in the reaction times in various cases and especially for various individuals were believed to be entirely due to "individual differences," the "degree of attention paid," as well as "practice" and "fatigue". When examined closely these interpretations can be considered nothing more than a refusal to supply a real explanation for these differences.

Donders[22] attempted to analyze the simple reaction's essential components earlier. Wundt did so as well, bringing into sharper focus certain elements from a mainly psychological perspective and condensing other elements whose division does not appear essential to a simple scheme which breaks the processes down into five subsections:

1. Centripetal [nervous] conduction from the sense organ to the brain.
2. Perception or entry into the field of consciousness (probably coinciding with the stimulation of the central cerebral sensory areas).
3. Apperception or entry into the focus of consciousness.
4. Volitional excitation and release of the movement being recorded.
5. Centrifugal [nervous] conduction from the brain to the reacting muscles and the accrual of energy for same.

Since then, this scheme has been essentially retained by psychometric experimenters in Leipzig. Meanwhile, Berger has justly emphasized

[22] *Archiv f. Anatomie und Physiologie* (1868), p. 664.

--- p. 498 / p. 499 ---

that steps two to four could undergo certain changes which would effect the validity of the scheme. “Lengthy practice shortens step four, the reaction then taking place ‘with greater mechanical certainty’ or as others might put it, ‘reflexively’. This last statement means that the stimulus to act [step four] is no longer expressly conscious. It appears that this can also be the case with the stimulus [step three]. One is often only first aware of the stimulus after having already actuated, indeed sometimes already after responding. Such a reaction can be represented thusly:

$$\left[1.\ 2.\ \left\{\begin{matrix}3. & \\ 4. & 5.\end{matrix}\right.\right]$$

meaning that a division after perception takes place. On one hand the movement is already connected to perception, on the other hand apperception also takes place at the same time.”[23]

The only objection to this automatic reaction of the adapted modification of Wundt’s system is that it is not radical enough. Volitional excitation which is “no longer expressly consciously” is not a true stimulation of the will, for the main criteria for an act of will is that it must be carried out in full consciousness. The formula $\left[1.\ 2.\ \left\{\begin{matrix}3. & \\ 4. & 5.\end{matrix}\right.\right]$, which should directly tie an “impulse” to perception, does not properly represent the automatic reaction better referred to as the muscular reaction. If we grant that Berger was correct that the muscular reaction does not include apperception, one must also go further and eliminate the stimulation of the will from the muscular reaction system. This form of the reaction is indeed nothing more

--- p. 499 / p. 500 ---

[23] *Philos. Studien,* vol. 3, p. 51. Compare Cattell, *Philos. Studien,* vol. 3, p. 322. Cattell’s reaction theory fits reasonably well with the muscular reaction and also confirms our theory of muscular reaction detailed below to a certain degree. Yet notably Cattell did not differentiate between ways of reacting and believed that “practice” explained everything.

than a brain reflex. When differentiated from the reflexes of lesser central [nervous system] organs (e.g., the spinal cord and the medulla oblongata) the entire act must precede the stimulation of the will each time (preparatory random excitation of the reaction movement) thus producing an act which in each of these cases is mechanical and without will. We must consequently deal with the physiological properties of this brain reflex and, when possible, also determine its path. Before we do this however, we should subject the sensory reaction styles to a thorough psychological assessment.

There is no doubt that Wundt's system can be applied without modification to extreme sensory reactions.[24] In particular it must be emphasized that subjective perception is made distinct by sensory reactions, for within the act [of reacting] we find first consciousness of the impression and thereafter the conscious will[25] to react.

I should like to make just one additional comment regarding the act of apperception (listed as number 3 above). According to Wundt's theory of apperception, active apperception of an expected stimulus consists of centripetal stimulus of the brain which is similar to and follows the stimulation of a sensory organ.[26] Both perception by the brain and by the sensory organ are conditioned by knowledge of its arrival.[27] In those cases in which these conditions were indisputably realized in each of our sensory experiments, I cannot help but think that reported perception

--- p. 500 / p. 501 ---

[24] It should be noted that the experimenter himself clearly recalls that his own reactions were predominantly sensory (*Phys. Psychologie* 2:3, p. 268).

[25] Noteworthy here is that although in general intent reacts directly after apperception, that is, before the sensory input takes place, nevertheless the actual, motor stimulation is once again accompanied by the subjective perception of the will and is not followed by a random reflex.

[26] [*Sinnesfläche* is variously translated as *sensory organs* or *sensory area,* as appropriate.]

[27] *Phys. Psychologie* 1:3, p. 233ff.

is also apperception. The length of time taken for apperception in our sensory experiments would therefore be zero.[28]

It would be different if there were no preparatory signal and the test subject deliberately avoided anticipating the primary signal. In such trials the act of reacting would certainly include a measurable apperception period. It is also certain that volitional excitation follows so much later that it is not easy to see which part of the delay is due to one or another part of the process. It seems to me that in experiments of this kind apperception can only be understood as a *passive* process. Yet if before each test run the subject is generally prepared and paying attention, his apperception could be taken as active apperception despite the fact that he had not been paying attention beforehand. During these experiments I had the subjective, if distinct feeling that despite the preceding act of will the test subject reacted afterwards absolutely *involuntarily and reflexively.*[29] For this reason the subsequent apperception is regarded more as passive, if also as arbitrary, preparatory passivity. If the test subject fails to make every effort to pay attention to the stimulus as soon as is possible and leaves it instead to chance as to how and when his attention follows the stimulus,[30] then apperception is certainly passive and indeed an unprepared, passive apperception.

--- p. 501 / p. 502 ---

Both kinds of passive apperception – randomly prepared and unprepared – indisputably take a certain amount of time, indeed the former more than the latter. In

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[28] [That is, hearing the bell in one's ear and in one's brain is, for these purposes, simultaneous. Prof. C. Green asks: If apperception requires zero time, then what is the point of Wundt's fractionating (reaction time) research program?]

[29] Despite preceding volitional intention, in the end it is involuntary and reflexive similar to the muscular reaction.

[30] Think, for example, of when you put down a newspaper and suddenly think of a name you believe you have never heard or read before only to discover that it came from the newspaper you just read.

contrast, in our sensory experiments with a signal (which only addressed active apperception after preparatory attention) apperception required no additional time whatsoever, as indicated earlier.

We now turn to a physiological consideration of the muscular reaction, whose extraordinary relation to common reflex movements has already been indicated. The single essential difference is that the reflex of the muscular reaction, no matter how involuntary, is the result of the preparatory influence of the will, in that it only takes place when the test subject is ready to react and consequently waits for preparatory innervation of the reacting muscle groups. How shall we make physiological sense of this preparatory influence of the will?

This much is known: although preparatory innervation indisputably comes from a voluntary movement center, the involuntary reaction itself must have its origin in a lower order center. That is to say, the voluntary movement center of the reacting muscle group W is outside the reflex path Sc_1Cc_2M, which leads from sensory organ S through the mediated central organ C to muscle group M.[31] Because the reflex cannot take place without voluntary preparatory movement innervation, however, we must assume that W is connected to C. Exactly how to understand the influence of W, can be explained by the following hypothesis which I believe has extraordinary potential.

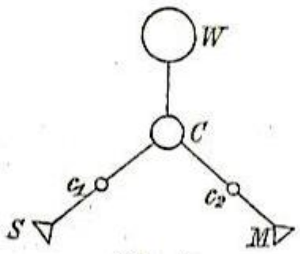

Fig. 2.

--- p. 502 / p. 503 ---

In the previous section I stressed that in no way should the degree of tension of certain muscle groups to the reaction be taken as criteria of preparatory movement

[31] In the accompanying figure c_1 and c_2 represent interpolated ganglia substance and is of secondary importance.

innervation. Such tension is indeed never completely arrested, but experience indicates that preparation with a minimal of tension can be just as good as a high degree of tension. Thus muscle tension should only be considered as something secondary. This fact leads us to the following supposition: *in the reaction the previous influence of W on C consists of W's transfer of a quantity of energy to C which is initially only potential for C although it is held in an unstable balance.* Now should a fairly strong stimulus pass from S to C this would be sufficient to upset this unstable balance. The freed energy would advance to M and produce visible muscle contractions. The weak muscle tension described above as secondary which precede the reaction are explained by virtue of the fact that W is not fully successful at making sure that the energy transferred to C is retained in its latent form. This is similar to a poorly closed container (e.g., an oxygen tank) whose pressure is gradually reduced by escaping air: C gradually releases small amounts of energy into M and it is this that activates those secondary muscle excitations.

The fact that both the arithmetic mean as well as the average variation of the measured times in muscular reactions is so extraordinarily much smaller as compared to sensory reactions is easily explained by the hypothesis that the first reaction must pass through much less grey matter.

It will also become evident why in muscular reactions (and never in sensory reactions) every distracting and distorting stimulus of a different kind always generates a response. We need only assume the existence of similar pathways from sensory organs S' and S" (Fig. 3) to

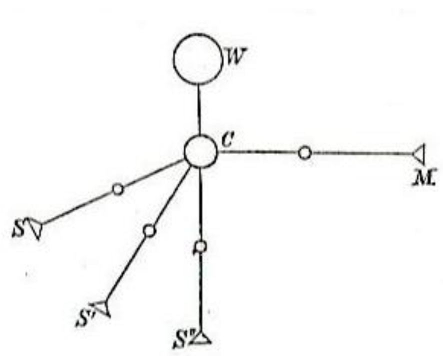

Fig. 3.

central point C. If there is latent energy in C (waiting to move toward M), any stimulus to C, regardless of whether it comes from S' or S", destroys the unstable balance.

Furthermore, the fact that premature registrations take place so easily in muscular reactions (and are altogether absent from extreme sensory reactions) is easily explained by merely assuming that C is also connected to the central sensory areas Σ, Σ', Σ" (Fig. 4). Given a series of rapid, successive muscular reactions separated by a constant interval, after a short time association of the stimulus inevitably appears in Σ with a delay matching the constant interval of the signal: the excitation bound up with this spreads to C and upsets the balance. It is then possible for a stimulus from Σ to arrive earlier at C, as compared to S and in these cases we get a premature registration.

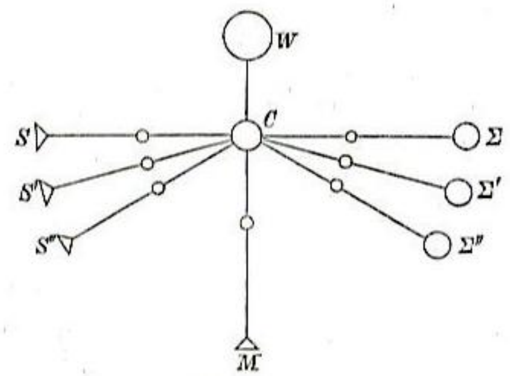

Fig. 4.

Finally, this theory is sufficiently developed to be able to explain one fact which I have not yet discussed. In muscular reactions it is difficult – but not completely impossible - to avoid the reaction movement being more than a reaction of only the specific body part, for example instead of the hand the entire arm (sometimes even the entire torso) is moved. Our hypothesis explains this by the fact that (just as some energy unintentionally flows from C to M)

--- p. 504 / p. 505 ---

C unintentionally radiates energy which W is only able to avoid with special effort.

We adopt from nerve physiology the generally accepted principle that any energy remaining from temporary functions of any kind at a higher center can be transferred to lower points. Indeed, only this kind of transfer can be explained by the involuntary and reflexive continuation of a deliberate movement. It also explains, for example, how when walking we are able to alter our path based on earlier decisions while, for example, simultaneously concentrating solely on other matters. It must be stressed, however, that recent research into the nervous pathways[32] has led to conclusions which agree with the hypothesis presented here.

This leads me to the question whether (based on the general physiological schema above) it is not possible to somehow locate these in the human nervous system - that is, to assign to W and C in particular specific locations within the brain. In fact observations from brain pathology fairly confirm that center W must lie within the central gyri[33] of the cerebral hemispheres.[34] As far as C is concerned, we can only speculate; I believe, however, that the following is as true as any argument in this hypothetical realm is currently capable of being.

In as much as a region of the brain is identical with C, we are able to make the following claims based on the research discussed thus far: this region must certainly be in contact

1. with various peripheral sensory organs, at the very least (so our research shows) with hearing, sight and touch;
2. with the corresponding central sensory areas in the brain

--- p. 505 / p. 506 ---

3. with the reacting muscle groups; and

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32 [*Leitungsbahnen* is alternately translated as *nervous system* or *nervous pathways*, as appropriate.]
33 [A convex fold or elevation in the surface of the brain.]
34 Wundt, *Physiol. Psychologie* 1:3, p. 167.

4. with the [brain] centers of voluntary contraction of these muscle groups.

When we examine more closely the construction of the human brain there are only two areas to consider:

a) the thalamus opticus, combined with the corpora quadrigemina[35],

b) the cerebellum

First, as concerns the combination of the thalmus opticus and the corpora quadrigemina, it appears there is in fact something to be said for C being located here. We know anatomically that optical nerves merge in the corpora quadrigemina with motor pathways originating in the spinal cord.[36] Physiological research is in complete agreement that aided by the corpora quadrigemina a reflective regulation of body movement can take place via visual perception.[37] Furthermore, the corpora quadrigemina's connection to the higher optical central areas is incontestable.[38] Finally, these ganglia are also connected to the cortical motor areas, at least via the thalmus opticus.[39] It appears that the muscular reaction to light can be explained by the mediation of the corpora quadrigemina. We claim, however, that while the muscular auditory and tactile reactions can be sufficiently explained by C, the corpora quadrigemina cannot explain them.

Just as a given central function does not always have to be strongly localized to a defined anatomical portion of the brain – and we too had to check our prejudice here from the beginning – C need not be identical with a single definable section of the brain. It is much more likely that various lower central regions divide C's function. In this sense one could make the claim that the

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35 [Term applied to the four protuberances on the dorsal surface of the midbrain; the two superior and two inferior colliculi.]

36 Wundt, *Physiol. Psychologie* 1:3, p. 144, 200.

37 Wundt, *Physiol. Psychologie* 1:3, p. 200.

38 Wundt, *Physiol. Psychologie* 1:3, p. 144.

39 Wundt, *Physiol. Psychologie* 1:3, p. 145.

thalamus opticus to a certain degree supplements the corpora quadrigemina. If in fact the thalamus opticus is the reflex center for tactile perception,[40] as Wundt assumes, then explaining the muscular tactile reaction taking into account the thalamus opticus should no longer present any problem. This is all the more so when taking into account the results of anatomic research into the connections of the thalmi which in general agree excellently with our description of C's function.

Only the meaning of the muscular reactions to *sound* remains to be resolved, as so far neither anatomical nor physiological research link the thalmus opticus to hearing.[41] In this regard, as anatomical and physiological research is anything but complete the possibility cannot be excluded that sound reactions have a special C, separate from the thalamus opticus and corpora quadrigemina (see above).

Let us see now whether C might be located in the cerebellum. Anatomically speaking, however, only the following has been established regarding the cerebellum:

a) the direct connection with the sensory spino-cerebellar tract: this would be in accordance with the postulated connection to the tactile organs
b) the connection with the motor regions of the cerebellopontine, that is, with the centers of voluntary muscular innervation.
c) the connection with the sensory regions of the cerebral cortex (cerebello-cortical pathway), that is, with the central sensory areas

And it is very probable that:

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[40] Wundt, *Physiol. Psychologie* 1:3, p. 204.
[41] Wundt, *Physiol. Psychologie* 1:3, p. 207.

d) a motor pathway to the spinal cord: this pathway would also comprise the postulated connection with the reacting muscle groups.[42]

--- p. 507 / p. 508 ---

Now, in order to be able to trace the muscular reaction for all three senses in question back to the cerebellum, in addition to the above conditions we must assume

e) a sensory link from the cerebellum to the optic nerve and

f) a similar link to the acoustic nerve.

Both of these pathways, however, follow what one presumes about the *physiological functioning* of the cerebellum.[43]

We freely admit that the data on the cerebellum presented here do not have a much greater probability than that for the thalamus opticus and corpora quadrigemina. At any rate, I believe a closer look at cerebellar functions with which we are already familiar contributes important reasons which will result in a preference for the cerebellum.

I fully subscribe to Wundt's view that the most important task of the cerebellum is to reconcile voluntary action with the position of the body in space by immediately (reflectively) triggering the correct motor innervations based on sensitive perceptional stimuli arriving in the cerebellum.[44] Now we know that when it comes to maintaining one's balance practice plays a particularly important role. This is so not only with children learning to walk, but also with adults when they try to maintain their equilibrium under difficult circumstance (e.g., on a horse, bicycle or tightrope) for an extended period of time. In fact, for someone learning to ride a horse those reflexes – critical to not being thrown – are little more than a combination of

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[42] Compare Wundt, Psychologie 1:3, p. 144*f.*

[43] Ibid., pp. 216, 217 [probably a reference to *Physiol. Psych.*].

[44] Ibid., pp. 206, 217 [ditto].

[complex] muscular reactions; for reflexes to take place correctly, initially one must concentrate in order to adjust to the animal's movements. It appears that the cerebellum only gradually gains independence from the cerebrum by, one presumes,

--- p. 508 / p. 509 ---

adapting its special metabolic needs to the often repeated and originally merely transmitted function thereby creating its own independent energy reserve.[45]

Following this, the cerebellum's balance reflexes are originally characterized by muscular reactions. In combination with the reasons emphasized earlier it seems plausible to assume that the central organ of muscular reaction is located in the cerebellum. Naturally, however, we are dealing here with an assumption and future research will confirm or refute it. One might, for example, test whether the muscular reaction remains the same when a galvanic current is run through the test subject's occiput.[46] If one were to find a considerable change this would increase the probability of the proposed hypothesis. Were such a test to produce the opposite result this would not totally disprove the hypothesis, but would nevertheless call it into question. At any rate, whether one finds the arguments made here convincing or not, with the material presented here we were nonetheless able to demonstrate that certain anatomical structures of the brain offer striking analogies to C.

After such a detailed, physiological discussion of the muscular reaction, one could expect something similar for the sensory reactions. I have emphasized, however, that as regards the *psychological* meaning of this reaction form I fully subscribe to Wundt's view. I believe that a localization of the accompanying

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[45] Incidentally, it appears as well that this independent energy reserve is maintained as such only through constant use. Thus one finds after long stays in a hospital that despite no noticeable muscle loss there are always difficulties walking and reestablishing one's balance.

[46] [Back part of the head or skull.]

psychophysical stimulatory process is not necessary as in this respect everything essential can be easily established.

--- p. 509 / p. 510 ---

The principal results of this section can be briefly summarized as follows:

1) In the sensory reaction which follows *preparatory attention,* perception and apperception probably coincide; this means that active apperception presumably takes no time at all.
2) The muscular reaction includes no apperception at all and just as little volition. It rather represents an involuntary, reflex movement, but one which takes place under the influence of the aftereffect of an *earlier* volitional impulse. The cerebellum may with a certain degree of probability be regarded as the mediating organ for this brain reflex.